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Hemipteran Hopper Species Associated with Acid Lime Plants (*Citrus aurantifolia* L .) in the Sultanate of Oman: Candidate Vectors of Witches'-Broom Disease of Lime

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مراقبة ورصد أنواع النطاط المتواجدة على أشجار الليمون الحامض في سلطنة عمان: محاولة للبحث عن ناقلات مرض مكنسة الساحرة

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الخلاصة: تناولت هذه الدراسة مراقبة تعداد مختلف أنواع حشرات النطاط المتواجدة في أشجار الليمون العماني باستخدام آلة شفط الحشرات. ولقد أجريت هذه الدراسة بمنطقة الباطنة في سلطنة عمان على مدى أربع سنوات، بهدف معرفة الناقلات الحشرية المحتملة لمرض مكنسة الساحرة في أشجار الليمون العماني. ولقد كانت الدراسة على مرحلتين: الأولى في الفترة من يناير 2000 م إلى مايو 2001م على أشجار ليمون مصابة بشدة في قرية الحبراء بولاية وادي المعاول، والثانية في قرية محارة في ولاية المصنعة في أحد المزارع الخاصة على أشجار ليمون كثيفة تبلغ سنة وسنتين من العمر وذلك من مايو 2001م، حيث كل الشتلات خالية من أعراض الإصابة ولمدة ثلاث سنوات حتى نهاية أبريل 2004م. أظهرت نتائج الدراسة تواجد نوع النطاط (*Hishimonus phycitis*) بأعداد أعلى من باقي أنواع النطاط الأخرى التي تم جمعها حيث وصلت نسبة ما تم جمعه من هذا النوع إلى 74.8%، في قرية الحبراء. وكان التعداد منخفضا في الفترة من يونيو إلى سبتمبر 2000م، ومن أبريل إلى مايو 2005م، و متوسطا خلال شهري أكتوبر ونوفمبر ومرتفعا نسبيا في الفترة من ديسمبر 2000م إلى مارس 2001م. أما في منطقة المصنعة فقد كانت الأعداد في حالة تذبذب خلال الفترة من سبتمبر إلى مارس من كل عام، وأعلى تواجد له كان في الفترة من يناير إلى مارس من كل عام. ولم يتم العثور على حشرت النطاط خلال فصل الصيف من أبريل إلى سبتمبر. كما رصدت ثلاثة أنوع وهي: النطاط *Circulifera* و النطاط *Toya* sp بأعداد مرتفعة نسبيا، وبلغت 10.4 و 3.8 و 2.4% على التوالي من Deltacephalinae و أحد النطاطات التابعة ل *haematiceps* مجموع الحشرات التي تم جمعها خلال السنوات الأربع. كما تم تسجيل تواجد تسع أنواع أخرى من النطاط وهي النطاط *Exitianus nanus* (Distant) والنطاط *Cicadulina* sp من النوع *chinai* (Ghauri) والنوع *storeyi* (China) والنطاط *Emposca distinguenda* (Paoli) والنطاط *Amrasca biguttula* (Ishihara) والنطاط *Deltocephalus (Recilia) pruthii* (Metcalf) والنطاط *Neolimnus aegyptiacus* (Mutsumura) وثلاث نطاطات Cicadellids (أحدها Deltacephaninae و الثاني Typhloceybinae و الثالث غير محدد). ولقد تم العثور هذه النطاطات التسعة بتعداد منخفض جدا حيث شكلت ما يقارب من 5% من مجموع النطاطات التي تجميعها خلال السنوات الأربع. تراوحت أعلى وأدنى درجات حرارة عند أقصى نشاط للنطاط بين 25 – 30 و 17 – 20 درجة مئوية على التوالي، بينما لم يكن هناك تأثير يذكر لدرجات الرطوبة النسبية. يعتبر *H. phycitis* الناقل الحشري الرئيسي المشتبه به في نقل مرض مكنسة الساحرة في الليمون العماني. لذا يقترح رش المبيدات *H. phycitis* النطاط الحشرية الجهازية بانتظام على أشجار الليمون العماني خلال الفترة من نوفمبر إلى مارس من كل عام للخفض أو الحد من تعداد الناقلات الحشرية بهدف منع أو تأخر انتشار المرض لأطول مدة ممكنة

ABSTRACT: Regular monitoring of hemipteran hopper species (including psyllids) associated with small-fruited acid lime trees (*Citrus aurantifolia* L.) was conducted for four years using motorized insect suction to determine the possible vectors of witches'- broom disease of lime (WBDL). The study was done in two phases: monitoring was done in Habra village, Wilayat Wadi AlMaawal (Batinah region) for one year from June 2000 to May 2001; then monitoring was done in Maharah village, Wilayat AlMusannah (Batinah region), for a period of three years from May 2001 to April 2004. Twelve species of cicadellid

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leafhoppers and one delpahacid planthopper species were collected, while no psyllids were found. *Hishimonus phycitis* (Distant) (Cicadellidae) was the most abundant hopper (78.4 % of collected individuals). Next in abundance were *Toya* sp. (Delphacidae), *Circulifera haematiceps*? and a deltocephalin leafhopper, respectively constituting 10.4, 3.8 and 2.4 % of the total catches of the four years. Nine other species made up 5% of the total collection: *Exitianus nanus* (Distant), *Cicadulina* sp. (either *chinai* (Ghauri) or *storeyi* (China)), *Emposca distinguenda* (Paoli), *Amrasca biguttula* (Ishihara), *Deltocephalus (Recilia) pruthii* (Metcalf), *Neolimnus aegyptiacus* (Mutsumura) and three undetermined species (one Deltocephalinae, one Typhlocybinae and one undeterminable to subfamily). Catches of *H. phycitis* were highest from November to March and lowest from May to September. There was a significant linear relationship between number of *H. phycitis* and maximum and mininmum temperature. Relative humidity was not significantly correlated to number of *H. phycitis*. In Maharah, young lime trees were free from WBDL but the disease incidence increased with age. *H. phycitis* is the best candidate vector of WBDL. The potential of *Toya* sp., *Circulifera haematiceps?* and an undetermined deltocephalin as candidate vectors is discussed. Finally, it is suggested that regular sprayings of acid lime trees with effective systemic insecticides during November to March each year can greatly reduce the vector population and can prevent or delay the spread of the disease to a great extent.

Keywords: Pytoplasma, leafhopper, vector, witches broom disease of lime, *Hishimonus phycitis*.

Introduction

The small-fruited acid lime trees (*Citrus aurantifolia* L.) locally known as "Omani lime" are grown throughout the Sultanate of Oman. In the Sultanate these trees have been suffering from a widespread and lethal disease called witches'- broom disease of lime (WBDL) caused by the phytoplasma (previously referred to as mycoplasma-like organism, MLO) *Candidatus* Phytomplasma aurantifolia (Bove, 1995). The name of the disease reflects its most conspicuous symptoms: dense growth of very small pale green leaves, highly proliferated shoots, and reduction in length of inter-nodes. The disease slowly spreads to all branches and then the branches start drying. Later the whole plant dries and eventually dies within five years of appearance of the first symptoms of the disease.

The disease appears to have been present in Oman since the 1960's. Symptoms of the disease were first clearly reported in the mid seventies from AlBatinah region (Moghal *et al*., 1996). The disease was officially recognized in the early eighties, and in the mid eighties it epidemically exploded (Moghal *et al*., 1996). The disease progressed and spread very fast in the Batinah region, but other regions of northern Oman have not been spared from the disease. It has already destroyed lime orchards, especially in the Batinah, killing thousands of infected trees (Garnier *et al.,* 1991; Bove, 1995), causing big losses to farmers. The disease is also found in the the United Arab Emirates and has recently been reported as destroying lime trees in Iran (Salehi *et al.,* 1997). The disease has also been reported from India (Ghosh *et al.,* 1999). Because of the rapid spread of the disease, an insect vector was suspected (Bove, 1995).

It is important to determine candidate vectors of WBDL as a first step in the process of arriving at the actual vector or vectors through transmission studies. To determine potential vectors of WBDL, we conducted regular monitoring of all the hemipteran hoppers (including psyllids) that are associated with acid lime trees in the Batinah. In addition, this study on the populations of hoppers associated with lime trees is expected to provide information on the peak acitivity period of the hoppers and will hopefully help in developing a suitable strategy to manage hoppers with the greatest potential to vector WBDL.

Materials and Methods

Sampling

Monitoring of populations of hemipteran hoppers (including psyllids), as potential vectors of WBDL, was done on acid lime trees at regular intervals at two farms in the southern Batinah. The study was done in two phases.

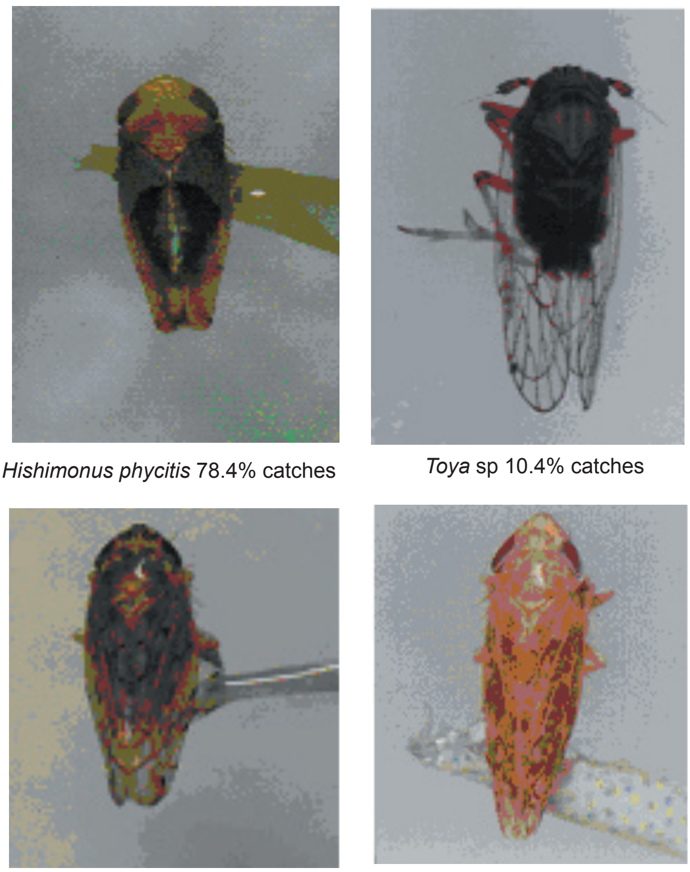
Phase I: Monitoring hoppers associated with WBDL in a highly infected lime orchard

Regular insect collections were done in an acid lime orchard highly infected with WBDL at Habra village (Wilayat Wadi AlMaawal, Batinah region) from June 2000 to May 2001 to provide preliminary information about the hoppers associated with WBDL. In this village the source of irrigation water was the *falaj* (spring water carried through ducts) and crops were flood-irrigated. Lime trees were more than 8 years old, closely spaced, and all were highly infected with WBDL.

Insects were collected by vacuuming 20 lime trees for one hour, twice a month. The insect collection was done using a back-pack motorized insect suction sampler (UNIVAC portable, Burkard Scientific Company, U.K.). Vacuuming of insects was done up to a height of two meters on each tree, covering the outer and inner plant canopy. All the hoppers collected were sorted, based on their morphological characters and the hoppers collected were pooled on a monthly basis. All the hopper species to be identified were numbered and preserved in 75% ethanol.

Phase II: Monitoring hoppers associated with a lime orchard intially free of WBDL

To have a more complete assessment of the insects associated with acid lime trees, 56 young (1-2 years old) and WBDL-free (results of polymerase chain reaction (PCR) were negative) Omani acid lime trees from a private farm in Maharah village, Wilayat Musannah (Batinah region) were selected in the year 2001. The plants were under well- irrigation using an irrigation line fitted with bubblers. The spacing between trees was 8 x 8.5 m and the area under the plants was cleanly cultivated. The presence of all the hoppers on these lime plants was monitored using an insect suction sampler (described above) twice a month, for one hour on each visit. On each tree, sampling was done up to a height of two meters, from both the outer and inner plant canopy. Monitoring was conducted for a period of three years, from May 2001 to April 2004. Collected hoppers were sorted, preserved in 75% ethanol, and unidentified forms



a) *Hishimonus phycitis* 78.4% catches

b) *Toya* sp 10.4% catches

c) *Circulifera haematoceps* 3.8% catches

d) *Deltocepalinae* 2.4 % catches

Figure 1 a-d. Four most abundant collected hoppers. a. *Hishimonus phycitis*. b. *Toya* sp. c. *Circulifera haematoceps*. d. undetermined deltocephalinae.

Table 1. Hopper species collected from witches'- broom diseased small fruited acid lime trees (*Citrus aurantifolia*) at Habra, Wilayat Wadi AlMaawal, Batinah region, Sultanate of Oman (June 2000 to May 2001). H. p. = *Hishimonus phycitis.* *Other hoppers – 1. *Circulifera haematoceps,* 2. Deltocephalinae (Cicadellid), 3. *Banus* sp, 4. *Exitianus nanus* (Distant), 5. *Cicadulina* sp either *chinai* (Ghauri) or *storeyi* (China), 6. indeterminable (Cicadellid), 7. *Toya* sp (Delphacid), 8. *Emposca distinguenda* (Paoli), 9. *Amrasca biguttula* (Ishihara), 10. Typhlocybiane: Empoascini (Cicadellid), 11. *Deltocephalus (Recilia) pruthii* (Metcalf), 12. *Neolimnus aegytiacus* (Matsumura).

Year/ Month	*H.p.*	Other Hopper Species Collected with Specimen Number*												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
2000														
June	10	2	0	0	0	0	0	0	0	0	0	0	0	12
July	7	2	12	0	1	5	2	0	0	0	0	0	1	30
Aug	10	7	0	0	0	0	0	2	0	0	0	0	0	19
Sept	9	3	0	0	0	0	0	0	0	0	1	0	0	13
Oct	18	0	0	0	0	0	0	0	0	0	0	0	0	18
Nov	13	2	0	0	0	0	0	0	0	0	0	0	0	15
Dec	49	0	0	0	0	0	0	0	0	0	0	0	0	49
2001														
Jan	50	0	0	0	0	0	0	0	0	0	0	0	0	50
Feb	38	0	0	0	0	0	0	0	0	0	0	0	0	38
Mar	35	0	0	0	0	0	0	0	0	0	0	0	0	35
April	10	5	0	3	0	1	0	0	0	1	0	0	0	20
May	3	6	1	0	0	0	0	0	1	0	0	0	0	11
Total	252	27	13	3	1	6	2	2	1	1	1	0	1	310
% of total	81.3	8.7	4.2	1.0	0.3	1.9	0.6	0.6	0.3	0.3	0.3	0.0	0.3	---

were numbered. Abundance of collected hoppers were recorded on monthly basis.

All unknown hopper species collected during the four years study were sent to the Natural History Museum, London, for identification.

Weather data and statistical analysis

Data on maximum and minimum temperatures and mean relative humidity were recorded daily at the Meteorological Observatory, Agricultural Experiment Station, Rumais, which is the nearest observatory to Maharah. These data were used to calculate corresponding monthly averages of maximum and minimum temperature and relative humidity, which were in turn tested for relationships with the catches of hoppers from Maharah through correlation and regression analyses. Correlation and regression analyses were done separately for each of the three years using the data analysis tool of Microsoft Excel.

Results and Discussion

Species composition and population dynamics

Phase I: Monitoring hoppers associated with WBDL in an infected lime orchard

Data on hoppers collected from Habra during June 2000 to May 2001 (Table 1) indicate that the most abundant hopper (81.3% of all specimens) caught on most collection dates was *Hishimonus phycitis* (Distant). This species was low in numbers during June to September 2000, with moderate numbers in October and November, and then reached peak catches from December 2000 to March 2001. With the onset of summer, the population started decreasing to low levels in April and May 2001. There were two other cicadellids, namely *Circulifera haematoceps* and an unidentified deltocephalin, both of which were caught in relatively large numbers (respectively 8.7 and 4.2

Table 2. Hopper species collected from initially healthy small fruited acid lime (*Citrus aurantifolia*) plant at Maharah, Wilayat AlMusannah, Batinah region, Sultanate of Oman (May 2001 to April 2002). H. p. = *Hishimonus phycitis*. *For names of hopper species see Table 1 caption.

Year/ Month	*H. p.*		Other Hopper Species Collected with Specimen Number*												Total
	A	N	1	2	3	4	5	6	7	8	9	10	11	12	
2001															
May	0	0	0	0	0	0	0	0	7	1	0	0	0	0	8
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Aug	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept	1	0	0	1	0	1	0	0	0	0	0	0	0	0	3
Oct	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Nov	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Dec	6	0	0	0	0	0	0	0	0	0	2	0	0	0	8
2002															
Jan	7	0	0	0	0	0	1	0	3	0	1	0	1	0	13
Feb	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Mar	5	0	0	0	0	0	1	0	52	0	0	0	0	0	58
Apr	9	0	0	1	1	0	0	0	1	0	0	0	0	0	12
Total	38	0	0	2	1	1	2	0	63	1	3	0	1	1	113
% of total	33.6	0.0	0.0	1.8	0.9	0.9	1.8	0.0	55.8	0.9	2.7	0.0	0.9	0.9	---

% of total catches). Nine more species of hoppers constituted 5.8 % of caught specimens. These were the delphacid *Toya* sp. and eight cicadellids, namely: *Banus* sp, *Exitianus nanus* (Distant), *Cicadulina* sp. either *chinai* (Ghauri) or *storeyi* (China), *Emposca distinguenda* (Paoli), a typhlocybin (Empoascini), *Amrasca biguttula* (Ishihara), *Neolimnus aegytiacus* (Matsumura), and a species undeterminable to sub-family. These latter nine sepcies were mostly caught in the summer months.

It can be hypothesied that hoppers, especially *H. phycitis*, managed to build up their populations and be present throughout the year because of the optimal microhabitat in the Habra orchard. This is probably due to (i) close spacing of lime trees which were shaded by tall date palms, (ii) intercropping, (iii) growth habit of WBDL-affected limes and (iv) flood-irrigation.

Phase II: Monitoring hoppers associated with a lime orchard intially free of WBDL

2001-2002: In addition to *H. phycitis*, nine other hopper species were collected during May 2001-April 2002, when the lime plants were apparently healthy and young (Table 2). They were the delphacid *Toya* sp, and the cicdaellids: *Banus* sp, *Exitianus nanus* (Distant), *Cicadulina* sp either *chinai* (Ghauri) or *storeyi* (China), *Emposca distinguenda* (Paoli), *Amrasca biguttula* (Ishihara), *Deltocephalus (Recilia) pruthii* (Metcalf), *Neolimnus aegytiacus* (Matsumura), and an unidentified deltocephalin.

Adult *H. phycitis* constituted 33.6 % of the total catches. The catches of this species in general were low but relatively high in December 2001, and in January and April 2002 (Table 2). On the other hand, *Toya* sp. numbers were exceptionally high, amounting to 55.8% of the total catches. Most of these (83%) were collected in March 2002. This indicates that there was a brood of *Toya* sp. which emerged in March 2002. The total catches of the other hoppers were very low, constituting together only 10.6% of total catches.

2002-2003: In the year May 2002 to April 2003, when the plants were 2-3 years old, the total catches of *H. phycitis* increased to 124 (Table 3) from 38 in the previous annual period. There were no catches of *H. phycitis* in May to September 2002. The catches were very low during October and November 2002 and April 2003. Most of the catches of this species ocurred during December 2002 to March 2003. The results obtained during this year indicated that,

Table 3. Hopper species collected from initially healthy small fruited acid lime plant (*Citrus aurantifolia*) at Maharah, Wilayat AlMusannah, Batinah region, Sultanate of Oman (May 2002 to April 2003). H. p. = *Hishimonus phycitis*. *For names of hopper species see Table 1 caption.

Year/ Month	*H. p.*		Other Hopper Species Collected with Specimen Number*												Total
	A	N	1	2	3	4	5	6	7	8	9	10	11	12	
2002															
May	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Aug	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Oct	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Nov	5	0	0	0	0	0	0	0	0	2	0	0	0	0	7
Dec	37	7	0	0	0	0	0	0	0	0	0	0	0	0	44
2003															
Jan	30	4	0	1	0	0	0	0	0	1	0	0	0	0	36
Feb	21	1	0	0	0	0	0	0	1	0	0	0	0	0	23
March	12	0	0	0	1	0	0	0	1	2	0	0	0	0	16
April	6	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Total	112	12	0	1	1	1	1	0	2	8	0	0	0	0	138
% of total	81.2	8.7	0.0	0.7	0.7	0.7	0.7	0.0	1.4	5.8	0.0	0.0	0.0	0.0	---

in addition to *H. phycitis*, six other hoper species were found on lime trees. They were the delphacid *Toya* sp., the cicdaellids: *Banus* sp, *Exitianus nanus* (Distant), *Cicadulina* sp either *chinai* (Ghauri) or *storeyi* (China), and *Emposca distinguenda* (Paoli) and an unidentified deltocephalin. *H. phycitis* was consistently seen in large number (adults and nymphs constituted 89.9% of total catches). These six other hopper species together constituted 10.1 %. Among the other hoppers, *Emposca distinguenda* was the most abundant, constituting 57% of all other hoppers caught (Table 3).

2003-2004: During the period extending from May 2003 to April 2004, the trend with regard to the catches of *H. phycitis* remained the same. Total numbers of this species increased to 178, which amounted to 93.5 % (adults and nymphs) of the total catches (Table 4). The other four hopper species caught were the delphacid *Toya* sp. and the cicadellids: *Emposca distinguanda*, *Cicadulina* sp., and an unidentified deltocephalin. Among these other hoppers, the most abundant (3.9 % of total catches) was *Toya* sp., which was caught only during January to March 2004.

General patterns

Composition of hopper species

Pooled data of hopper species on acid limes for the four year study is presented in Table 5 for comparison. No psyllids were caught during the four years. The total catch of *H. phycitis* was very high (581 specimens), representing 78.4 % of the total catches. Twelve other hopper species were collected during the four years study. Among these, three hopper species were caught in relatively large numbers: *Toya* sp (74 specimens), followed by *Circulifera haematiceps* (27 specimens) and undetermined deltocephalin (17 specimens) (Table 5). Fig.1 a-d shows the latter four most abundant hoppers. Other less abundant leafhopper species were: *Emposca distinguenda* (Paoli), *Cicadulina* sp (either *chinai* (Ghauri) or *storeyi* (China)), *Banus* sp., *Amrasca biguttula* (Ishihara), *Exitianus nanus* (Distant), *Neolimnus aegyptiacus* (Mutsumura), undetermined (Cicadellid), *Deltocephalus (Recilia) pruthii* (Metcalf), and undetermined Typhloceybin. These latter nine species were extremely low in numbers, over a period of four years, suggesting that

Table 4. Hopper species collected from initially healthy small fruited acid lime plant (*Citrus aurantifolia*) at Maharah, Wilayat AlMusannah, Batinah region, Sultanate of Oman (May 2003 to April 2004). H. p. = *Hishimonus phycitis*. *For names of hopper species see Table 1 caption.

Year/ Month	*H. p.*		Other Hopper Species Collected with Specimen Number*												Total
	A	N	1	2	3	4	5	6	7	8	9	10	11	12	
2003															
May	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
Sept	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	1	0	0	0	0	0	1	0	0	1	0	0	0	0	3
Nov	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Dec	16	3	0	0	0	0	0	0	0	0	0	0	0	0	19
2004															
Jan	30	11	0	0	0	0	0	0	1	0	0	0	0	0	42
Feb	38	3	0	0	0	0	0	0	4	0	0	0	0	0	45
March	30	3	0	0	0	0	0	0	2	0	0	0	0	0	35
Apr	27	1	0	0	0	0	0	0	0	0	0	0	0	0	28
Total	146	21	0	1	0	0	1	0	7	2	0	0	0	0	178
% of total	81.7	11.8	0.0	0.6	0.0	0.0	0.6	0.0	3.9	1.1	0.0	0.0	0.0	0.0	---

they cannot be the vectors of WBDL, given the rapid rate of disease spread.

Possible vectors of WBDL

Since *H. phycitis* was collected in large numbers and was present on most of the collection dates, it appears that it may be the most likely vector of WBDL, as also suggested by Bove *et al*. (1988) and Koizumi (1995). Furthermore, this insect was also reported as a vector of phytoplasma disease on other crops. In plants such as periwinkle (*Catharanthus roseus*) it transmits periwinkle little leaf disease (Kar and Panda, 1990). In India it is known to transmit a phytoplasma disease called little leaf disease of eggplant (Srinivisan and Chelliah, 1978). Interestingly, *H. phycitis* has long been known in India, and acid lime is known as one of the hosts plants on which this leafhopper is able to live and multiply (Bindra and Singh, 1969). Thus *H. phycitis* is the number one candidate, but the presence of three more hopper species (*Toya sp*, *Circulifera haematiceps* and an undetermined Deltocephalin) in significant numbers means that these species should be considered as candidates vectors no. 2, 3 and 4 for WBDL. Since *H. phycitis* is considered as the number one candidate vector, we will focus on its population dynamics and the weather conditions during its peak population period.

Population dynamics of* H. phycitis *and effects of temperature and relative humidity

The population fluctuations of *H. phycitis* during the four year study are depicted in Fig. 2. It clearly shows that population fluctuations followed similar trends during the four years. The peak activity period was between November and March, while the population decreased to low levels between April and September.

H. phycitis catches and the maximum and minimum temperatures during each of three year annual periods in Maharah are plotted together in each of Figs.3 a-c, which indicate that the maximum and minimum temperatures during the peak activity periods of *H. phycitis* ranged from 25 to 30 ^{o} C and from 17 to 20 ^{o}C, respectively.

In order to determine whether there was an association between temperature and relative humidity on the one hand and *H. phycitis* numbers on the other hand, the monthly catches of *H. phycitis* during the three year study at Maharah were correlated with monthly

Table 5. Hopper species collected from Habra (Wilayat Wadi Almaawal, Batinah) and from Maharah (Wilayat AlMusannah, Batinah). * Other hopper species : 1. *Circulifera haematoceps,* 2. Deltocephaline (Cicadellid), 3. *Banus* sp, 4. *Exitianus nanus* (Distant), 5. *Cicadulina* sp either *chinai* (Ghauri) or *storeyi* (China), 6. indeterminable (Cicadellid), 7. *Toya* (Delphacid), 8. *Emposca distinguenda,* (Paoli), 9. *Amrasca biguttula* (Ishihara), 10. Typhlocybiane: Empoascini (Cicadellid), 11. *Deltocephalus (Recilia) pruthii* (Metcalf), 12. *Neolimnus aegytiacus* (Matsumura).

Location and period	Plant age (years)	Plant conditions	*H. phycitis*	Other Hopper Species Collected with Specimen Number*												Total
				1	2	3	4	5	6	7	8	9	10	11	12	
Habra June 2000 to May 2001	>8	All plants infected with WBDL	252	27	13	3	1	6	2	2	1	1	1	0	1	310
Maharah May 2001 to April 2002	2-3	6 out of 56 plants infected with WBDL	38	0	2	1	1	2	0	63	1	3	0	1	1	113
Maharah 2002 to April 2003	3-4	11 out of 56 plants infected with WBDL	124	0	1	1	1	1	0	2	8	0	0	0	0	138
Maharah 2003 to April 2004	4-5	14 out of 56 plants infected with WBDL	167	0	1	0	0	1	0	7	2	0	0	0	0	178
Total			581	27	17	5	3	10	2	74	12	4	1	1	2	739
% of total			78.4	3.8	2.4	0.7	0.4	1.4	0.3	10.4	1.7	0.6	0.1	0.1	0.3	----

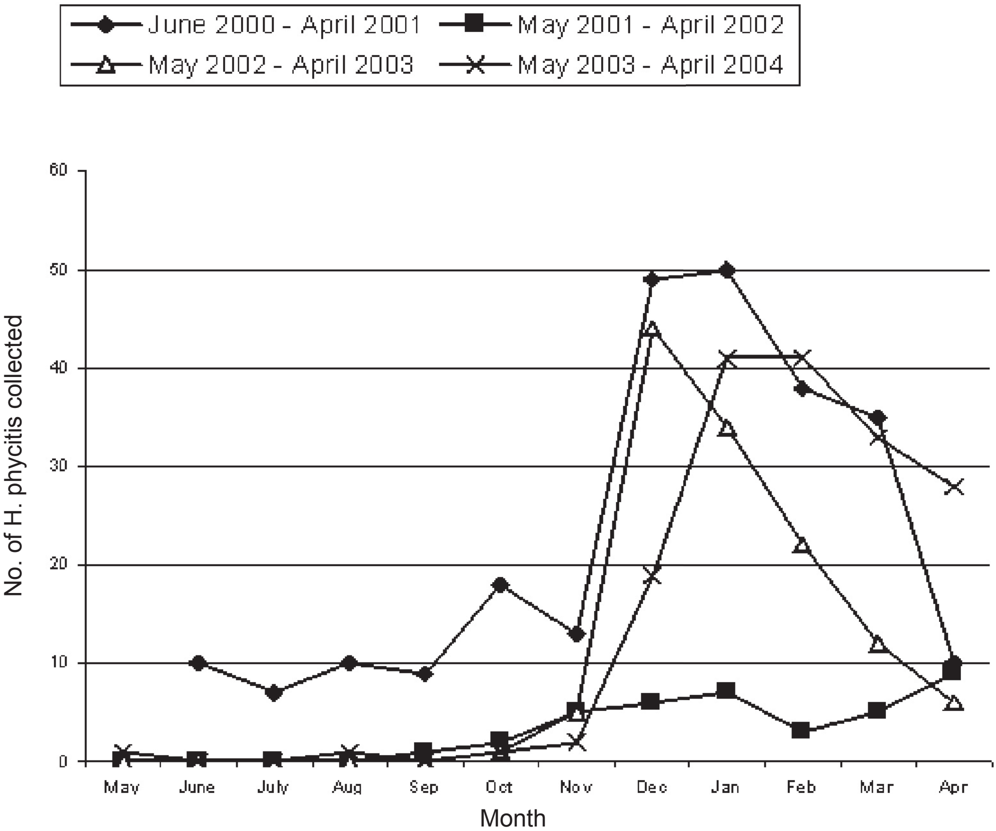


Figure 2. Population fluctuations of *H. phycitis* on small fruited acid lime plants (June 2000 to April 2004).

average maximum and minimum temperatures and with relative humidities. It is evident that a significant negative correlation existed between the catches of *H. phycitis* and maximum and minimum temperatures. The 'r' values for the regression of catches against maximum and minimum temperatures during the year 2001-2002 were -0.64 and -0.70 ($p<0.05$), respectively (Table 6). The 'r' values for the regression of catches against maximum and minimum temperatures during the year 2002–2003 and 2003-2004 were -0.82 and -0.82 ($p<0.01$), and –0.68 ($p<0.05$) and –0.76 ($p<0.01$), respectively (Table 6). The 'r' values for maximum and minimum temperatures of the three years pooled data were –0.62 and -0.66 ($p<0.05$), respectively. Relative humidity did not show any significant correlation with numbers of *H. phycitis* (Table 6). Linear regression analysis was conducted to predict population numbers of *H. phycitis* from mean maximum and minimum temperatures based on pooled data from the three years of monitoring in Maharah. The linear equations and regression lines are presented in Figure 4.

Relationships between* H. phycitis *population and the age and disease condition of lime trees

In Maharah total catches of *H. phycitis* were low in numbers (38) when the plants were young (2-3 years old) and increased with age. The number of specimens caught was 124 when the plants were 3-4 years old, and increased to 167 when the plants attained the age of 4-5 years. The *H. phycitis* total annual catch recorded in Habra (252) was relatively higher than the other 3 annual catches recorded from Maharah. The Habra orchard had infected plants eight years and older in age. Direct comparisons cannot be made between Habra and Maharah. However, due to the close proximity of the two locations, the data from Habra provides some support to the idea that the population of *H. phycitis* in Maharah could have increased with

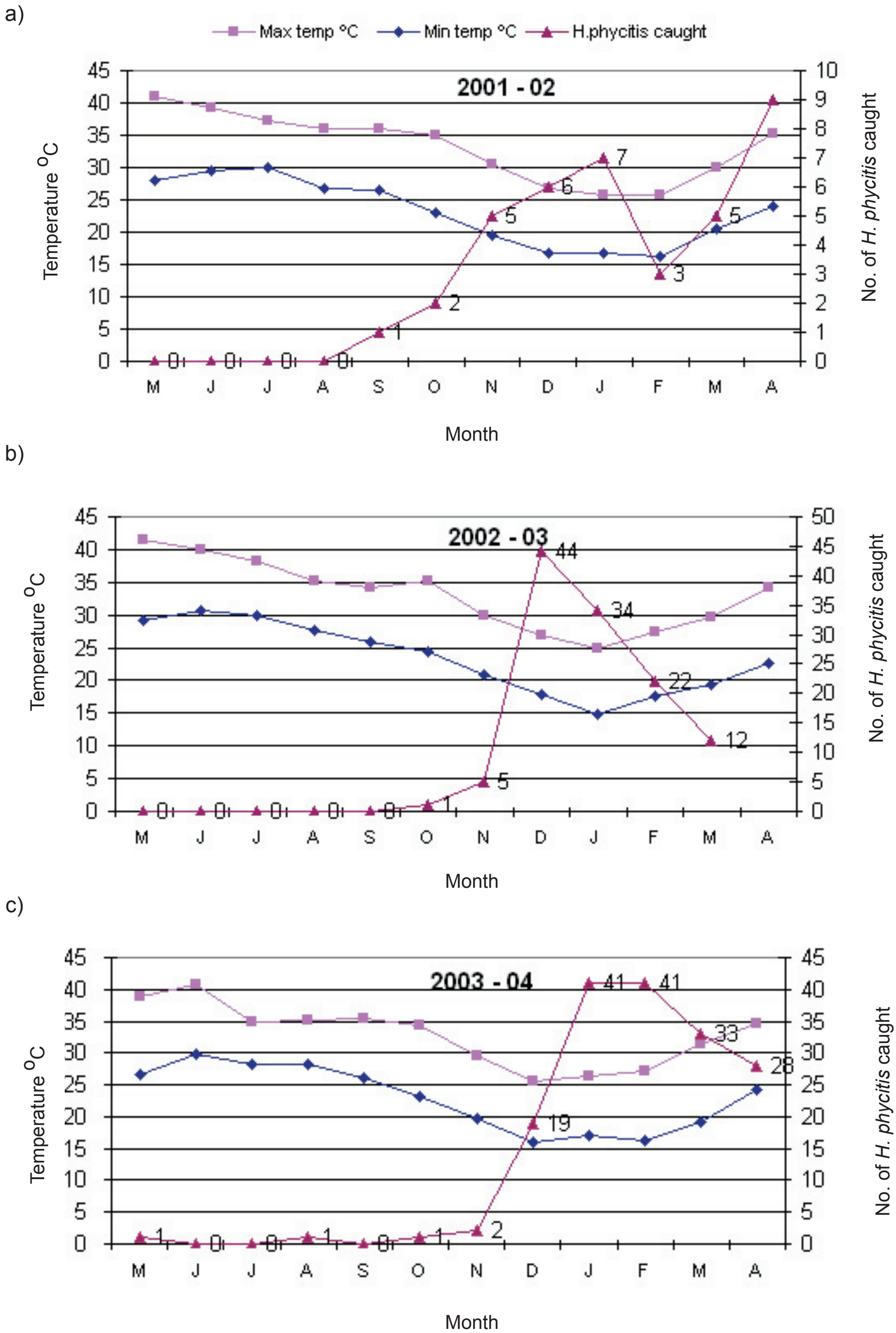
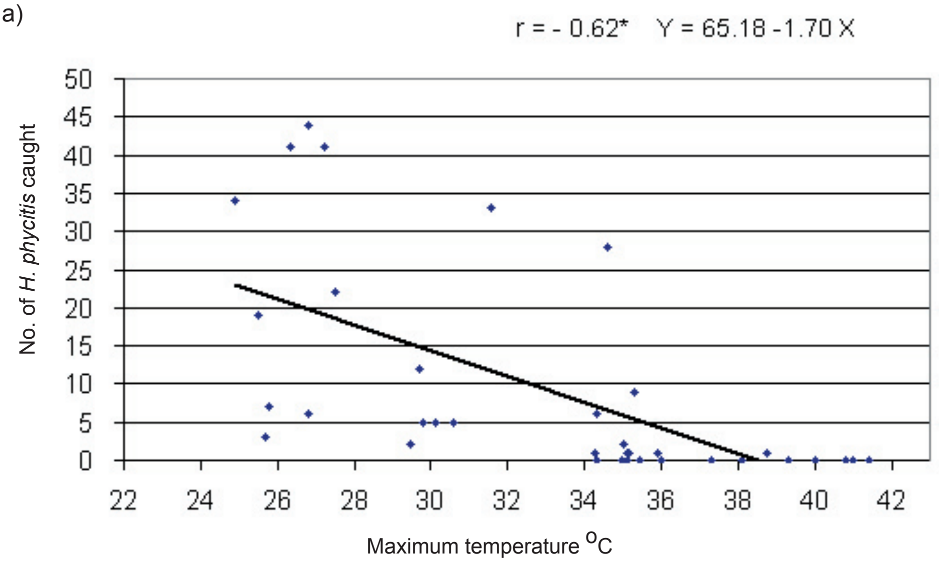


Figure 3a-c. Effect of temperature on the population fluctuations of *H. phycitis* on lime trees in Maharah (Al Musanah Wilayat) from May 2001 to April 2004.

a)



b)

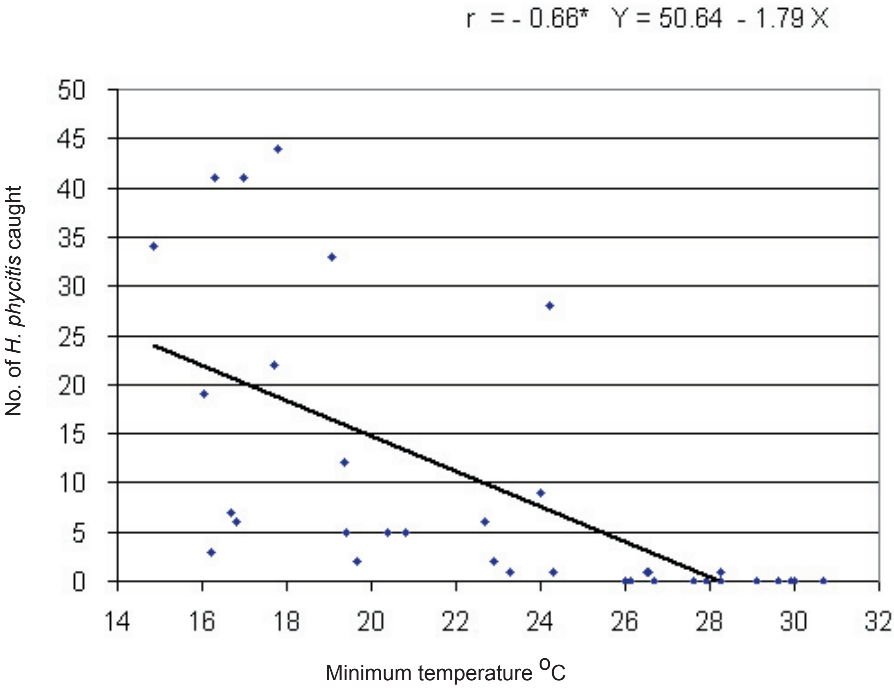


Figure 4 a-b. Relationship between the catches of *H. phycitis* and maximum and minimum temperatures in Maharah (Al Musanah Wilayat) from May 2001 to April 2004. a) Relationshp with maximum temperature. b) Relationship with minimum temperature.

Table 6. Correlations between catches of *Hishominus phycitis* and weather factors at Maharah (May 2001 to April 2004). *Significant at α=0.05. ** Significant at α=0.01. NS = not significant.

Year	Mean Catches ±SD	Temperature °C Maximum Mean ±SD	Maximum Correlation Coefficient r	Minimum Mean ±SD	Minimum Correlation Coefficient r	Mean Relative humidity % Mean ±SD	Relative humidity Correlation Coefficient r
2001-02	3.2 ± 3.2	33.2 ± 5.3	-0.64*	23.1 ± 5.1	-0.70*	55.4 ± 8.0	-0.13 NS
2002-03	10.3 ± 15.1	33.1 ± 5.3	-0.82**	23.4 ± 5.4	-0.82**	60.8 ± 11.1	0.10 NS
2003-04	13.9 ± 17.3	32.8 ± 4.9	-0.68*	22.9 ± 5.1	-0.76**	56.4 ± 9.9	-0.11 NS
Pooled analysis	9.1 ± 13.7	33.1 ± 5.0	-0.62*	23.1 ± 5.0	-0.66*	57.5 ± 9.8	0.03 NS

the increase in age of lime trees, possibly due to the increase of plant canopy with age. This could have provided more congenial micro-climatic conditions for the *H. phycitis* to build up its population.

The catches of *H. phycitis* were very high in plants infected with WBDL in Habra (Table 1). It appears that this leafhopper species has a preference to feed, thrive and multiply on diseased branches. The exact reason is not known. However, the diseased branches have soft tissues, smaller leaves, and reduced internodes. This could make microenvironmental conditions more congenial for the hopper to build up its population. Another explanation for the preference of *H. phycitis* for diseased parts of lime trees is the altered physiology of diseased host tissues, as suggested by Srinivasan and Chelliah (1979) and Raghuraman (1968). Srinivasan and Chelliah (1979), while studying the biology of *H. phycitis,* found a significant difference in incubation period, nymphal period and adult longevity between healthy and little-leaf diseased eggplants. According to these authors the adult longevity of *H. phycitis* was significantly longer on diseased plants (23 days) than on healthy plants (9 days). A similar finding was made by Murral *et al.* (1996) who reported that the aster leafhopper *Macrosteles quadrilineatus* lived longer on aster yellow phytoplasma-diseased plants than on healthy plants.

Progress of WBDL in Maharah

All 56 plants at Maharah in 2001 (start of the study) were free from WBDL. Six plants started showing

Table 7. Appearance of witches'- broom disease of lime (WBDL) in small fruited acid lime plants (*Citrus aurantifolia*) on which hopper species were monitored (at Maharah during 2001 – 2004).

Plant Age (yrs)	No. of Plants Showing Symptoms of WBDL in the Month of JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total No. of Pants with WBDL Symptoms	Cumulative Total of WBDL Infected Plants	% Plants Showing WBDL Symptoms
2	All plants were free from symptoms of WBDL												0	0	0.0
3	0	0	0	0	3	0	3	0	0	0	0	0	6	6	10.71
4	0	0	0	0	0	2	2	1	0	0	0	0	5	11	19.64
5	0	0	0	0	0	0	2	1	0	0	0	0	3	14	25.00
Total	0	0	0	0	3	2	7	2	0	0	0	0	-	-	-

symptoms of WBDL at the age of three years. As time passed more plants started showing symptoms and by 2004, 14 plants (25% of all plants) showed symptoms of WBDL (Table 7). It is also interesting to note that new records of symptomatic trees were made during the hotter months (May to August) in each of three years of monitoring in Maharah (Table 7).

Practical implications of the study

Because *H. phycitis* is the predominant hopper (Table 5) and was present on most collection dates (Fig. 2), it is the top potential vector. It is also clear from Figure 2 that during the entire four years study, the population of *H. phycitis* was mostly observed during November–March. It is suggested that regular applications of effective systemic insecticides during this peak population period could control the population of the vector and consequently may check the spread of WBDL.

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